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RATE OF SOLUTION OF SULPHATE OF ALUMINUM[1]

By J. W. Ellms,[2] A. G. Levy[3] and L. A. Marshall[4]

A knowledge of the time required to dissolve a given quantity of sulphate of aluminum is essential to the proper design of solution and storage tanks required in water purification plants, where this chemical is employed and applied as a solution to the water to be treated. In connection with the design of tanks for a large filter plant for the City of Cleveland, the authors undertook some experiments on a small and large scale with the idea of securing such information as would be necessary to determine the proper size for these tanks.

In 1897, A. A. Noyes and W. R. Whitney[5] showed that the rate of dissolution of a solid in a solvent was an extremely rapid process, but that the rate of diffusion of the solution formed was comparatively slow. It is the slower diffusion which determines the observed, i.e., the apparent, rate of dissolution of the solid. These investigators concluded that the solid substance when immersed in the solvent immediately became surrounded by a very thin layer of saturated solution, which slowly diffused into the solvent not in contact with the solid. Their hypothesis was fully borne out by their experiments, and has been confirmed since by other investigators.

Obviously there are several important deductions which may be made from these general principles:

(1) The greater the surface area of the solid to be dissolved, the larger the quantity of saturated solution there will be ready for diffusion into the body of the solvent.

(2) The more quickly the saturated surface layer can be removed by diffusion, the more rapidly will a new surface layer form.

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[5] Zeitschrift physik. Chem., 23, 689, 1897.

The practical conclusions are, therefore, (*a*) that the solid should consist of many small particles, i.e. be finely ground or crushed; and (*b*) that diffusion must be hastened by the utilization of some extraneous force.

The application of these general principles to the problem of dissolving a given amount of sulphate of aluminum within a definite time, in correctly proportioned tanks, and with the utilization of a minimum amount of energy, was the basis of the experimental work.

Two general methods of producing solutions are at once apparent: (1) The movement of the solute in the solvent, and (2) the passage of the solvent through the mass of the solute. The first condition is exemplified in the ordinary mixing tanks containing motor-driven paddles and rakes; while the second is illustrated by the upward passage of water through the channels formed between the lumps of the chemical to be dissolved.

The mechanical agitation of the solid in the solvent by means of motor driven stirrers has certain obvious drawbacks. From the operating standpoint, power is constantly required, the alum solution is more or less corrosive in its action on metals, and the motors and machinery require some degree of skilled attention. From the point of design, the stirring machinery must be of rather heavy construction and the motors of relatively large capacity, especially if large amounts of alum are charged into the solution tanks at once or at frequent intervals. This means high first cost and consequently high interest and depreciation charges. In view of these facts, it was felt that a better method of producing solution, provided the plan was found practical for use on a large scale, would be to rely on a continuous flow of water up through the solid, the latter being supported on a grid in the solution tank. By this method, distribution of the saturated layer into the body of the solvent would depend upon the movement of the water as it made its way upward through the ground or crushed alum.

If the latter method is followed, however, it is evident that the total quantity of water used must not be greater than will just fill the storage tank into which the solution is discharging. Provided the chemical can all be dissolved in the time required to fill the storage tank, the rate of application of the water may be varied between rather wide limits. These limits range from that of practically instantaneous filling of the tank on the one hand, to that of partly filling it on the other. There still must be allowed, however, a sufficient margin of time, before cutting the tank into service, so that the completion of the filling may be made rapidly from an auxiliary source of supply.

With these limitations in mind, and assuming the desired capacity in the storage or supply tank for the finished solution, and a solution tank of sufficient size to hold the alum charge to be dissolved, the problem is, will it be possible to dissolve all of the alum by the time the storage tank is full?

Several different pieces of experimental apparatus were constructed for measuring the dissolution velocity of the alum. In each apparatus, however, the principle of an upward flow of the water through the alum supported on a grid, was used. The principal apparatus consisted of a wooden box with inside dimensions of 4 inches by 4 inches by 70 inches in height. A perforated wooden grid was placed 13 inches above the bottom. Overflow pipes were provided on one side near the top. The water was admitted to the chamber underneath the grid.

TABLE 1

Effect of change of size of alum on rate of solution, expressed as height in inches of column of alum at different stages of the experiment. Rate of flow, 5.04 inches vertical rise per minute. Temperature, 10°C.

STAGE OF EXPERIMENT	LUMP, COARSE AND FINE AS RECEIVED	PASSED ¾ INCH MESH LEFT ON ½ INCH	PASSED ½ INCH MESH LEFT ON ¼ INCH	PASSED ¼ INCH MESH
Start	29⅜	30½	31	27¼
After 10 minutes	25	22¼	18	6
After 30 minutes	16⅜	8½	3¾	1
After 60 minutes	8⅞	⅝	⅛	0
After 90 minutes	3¼	0	0	
After 120 minutes	1⅜			

Usually a column of lump alum about 30 inches in height was placed in this device, and the time required to dissolve it at different rates of flow, was determined. The rates of flow used varied from 2.52 inches to 10.08 inches per minute, corresponding to tanks in the proposed design that would be filled in 4 hours to 1 hour. Intermediate rates of 3.36 inches and 5.04 inches vertical rise per minute (corresponding to 3 and 2 hours, respectively, for filling the tank) were also tried. Graded sizes of alum were experimented with and showed clearly the effect produced by increasing the surface area of the solute exposed to the solvent. The results given in table 1 will show this effect.

Experiments made on two pieces of alum set in paraffin, which maintained a practically constant surface area exposed to the water, but whose actual areas differed in the ratio of 1 to 4, showed losses in the same ratio when exposed to water flowing at the rate of 6.3 inches per minute. It was also found that if the water flowed past these pieces of alum at a rate four times as fast, the actual loss and the ratio of the losses from the pieces, was practically the same as at the lower rate of flow. This would indicate that the quantity of alum dissolved in any given time is directly proportional to the area exposed to the solvent, and, within the rates of flow which were employed, practically independent of the velocity. In other words, the rate of diffusion was not appreciably affected by the variation in the vertical rise of the water used.

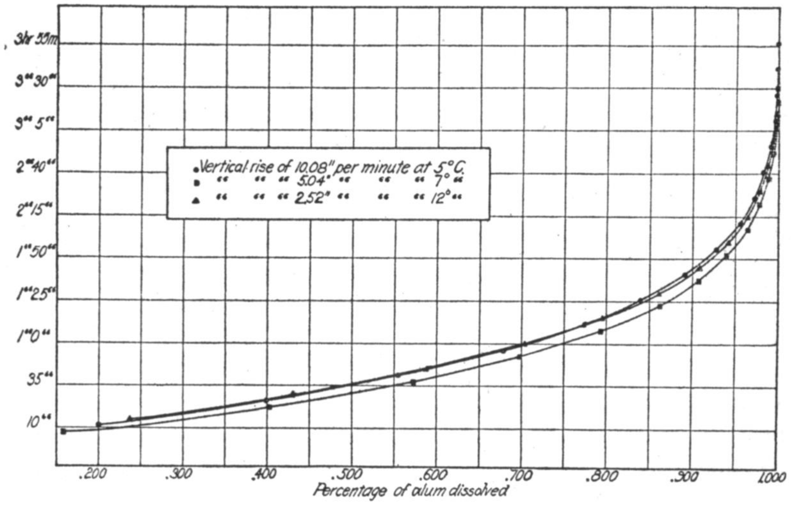

FIG. 1

This relationship is also well brought out in the set of curves shown in figure 1. For three different rates of flow, practically the same proportion of the total charge was dissolved in equal lengths of time. The reason for the curves not coinciding exactly is probably due to the fact that, in addition to the temperature variation, the experiments were made with run of crusher alum, in which the ratio of surface to volume was not the same due to variations in the proportions of the different sized pieces.

The effect of temperature on the rate of dissolution was studied experimentally on pieces of alum 25 mm. square set in paraffin, as previously explained, and subjected to the action of water flowing at the same velocities but at differing degrees of temperature. One set was run through at a temperature of 4°C. and another at a temperature of 23°C. At 4°C., the loss per square mm. was 0.00418 grams, and at 23°C., it was 0.00828 grams. In other words, with a difference of 19°C., the rate of dissolution at the high temperature was nearly twice as fast as at the low temperature. Two other experiments, which had been run for different purposes, at approximately 7°C. and 13°C., showed losses per square millimeter which fell approximately on the straight line connecting the losses given above for 4°C. and 23°C. This would seem to indicate that the effect of temperature on the rate of dissolution is a straight line function, increasing approximately 5 per cent per degree Centigrade increase in temperature.

To study the effect of depth on the dissolution velocity, water was first passed through 30 inches of alum and then through 15 inches, and the time required in each case to completely dissolve the chemical was found to be practically the same.

In order to carry out experiments on a large scale, a perforated wooden grid was placed in a steel tank 6.5 feet in diameter and 3.5 feet deep. The top of the grid was 11 inches above the bottom of the tank, and the overflow 25 inches above the grid. Water was admitted to the under side of the grid. The area of the grid was 33.5 square feet, and was filled with $\frac{3}{4}$ inch circular holes, placed on 3-inch centers.

Two tons of crushed alum were placed on the grid, and water forced up through the mass. The alum stood at a depth of 16.5 inches before applying the water. The water was forced up through the alum at a rate of 2.5 inches per minute. At the end of 15 minutes, the pile of alum had diminished in depth 6 inches, at the end of 30 minutes, 11 inches, and at the end of an hour, 15.5 inches. At the end of two hours, the tank was drained, and all that was found on the grid was 6 pounds of wet gummy matter, which covered a considerable area of the boards to a depth of $\frac{1}{4}$ to $\frac{1}{2}$ inch. This material readily dissolved on a wire grid when placed in a glass cylinder, showing that it was soluble, if the dissolving water came in contact with it in the proper way. Hosing this gummy residual matter, which was left in the tank in a second experiment, showed that it could readily be dissolved if the hose stream had force enough to disintegrate it. The practical conclusion is, that the grid must be properly designed so that, while it will support a load of alum of the desired fineness, it will still permit of an upward flow of water at as many points as possible, leaving as few dead areas as practicable.

The conclusions reached in this investigation are as follows:

1. That basic sulphate of aluminum in lump form as ordinarily sold, may be readily dissolved in upward flow solution tanks in a reasonable length of time.

2. That, where such tanks are used with a vertical rise of water at a rate of 2.5 to 10 inches per minute, and a temperatue of about 7°C., run of crusher alum, having pieces not exceeding 2 to 3 inches in diameter, may be completely dissolved in from 3½ to 4 hours.

3. That, under the same conditions as in the preceding statement, but at a temperature of 10°C., crushed alum with sizes of pieces varying from ½ inch to ¾ inch may be dissolved in practically 1½ hours, while pieces ¼ inch to ½ inch in diameter may be dissolved in one hour.

4. That the rate of dissolution, or more properly diffusion, was not materially different for the rates of flow used, namely 2.5 to 10 inches vertical rise per minute.

5. That, for all practical purposes, provided the point of saturation is not reached by the solvent (water) in passing through the column of alum in upward flow tanks, within the limits of these experiments, viz: 2.5 to 10 inches vertical rise per minute, the length of time required to dissolve alum in any given condition is a factor only of the temperature of the water and of the size of the pieces of alum, and is independent of the total weight of alum to be dissolved.

6. That the depth of alum which may be used in upward flow tanks without the solvent becoming saturated before reaching the top, may be determined approximately (keeping in mind the experimental limits of vertical flow) from the results obtained, namely, that run of crusher alum dissolves, in water having a temperature of about 7°C., at the rate of approximately 2 per cent of its depth per minute; alum crushed to the size of ½ inch to ¾ inch pieces, using dissolving water at a temperature of 10°C., at approximately 4 per cent of its depth per minute; and alum composed of pieces ¼ inch to ½ inch in diameter, using the same temperature (10°C.) of the

dissolving water, at a rate of approximately 7 per cent of its depth per minute. With a depth of alum of approximately 5 to 6 inches, and which has been crushed finer than ¼ inch, the solvent will become saturated by the time it reaches the top of the column, when the vertical rise is 5.04 inches per minute and the temperature 10°C.

7. That, for each degree Centigrade change in temperature, the rate of dissolution of alum, and consequently the time required to dissolve the alum, will vary approximately 5 per cent, the time decreasing with an increase in temperature.

8. That, with a knowledge of actual velocity of solution under the practical conditions imposed in these experiments, it becomes a comparatively easy matter to properly determine both the actual and relative sizes for the solution and storage tanks.

9. That the design of the grid supporting the alum should be such as to leave as few dead areas as possible.